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Positron Annihilation in a Zirconium Single Crystal*

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The angular distribution of the γ quanta emitted in the two-photon annihilation of positrons in zirconium has been measured along the (0001) direction of a single crystal. The results are compared with calculations by Gupta and Loucks in the augmented-plane-wave approximation. The data confirm that the curve at small angles falls significantly below the parabola expected for a free-electron gas and that there is a conspicuous contribution at large angles from the high-momentum components of the electron wave function. A small hump predicted near the zone boundary was not resolved.

Gupta and Loucks[1] calculated the angular distribution of the radiation from the two-photon annihilation of positrons in yttrium and zirconium. The work was based on a study of the electronic structure of these transition metals in an augmented-plane-wave approximation.[2,3]

The interest of a comparison between zirconium and yttrium lies in the fact that the calculations for yttrium show a pronounced hump in the angular correlation curve at angles of 2.5 mrad which corresponds to the position of the zone boundary, whereas for zirconium with one more electron in the d shell, the hump is predicted to almost disappear. The theory for yttrium is in reasonable agreement with the measurements by Williams and Mackintosh,[4,5] but no data on zirconium were available until now.

We have measured the angular correlation curve for a zirconium single crystal in a standard angular correlation instrument with a resolution of about 0.5 mrad. The crystal, approximately 3 mm diam and 2 mm thick, was cut such that the (0001) direction was parallel to p_z, the momentum component measured by the angle $\theta = p_z/mc$. The small area of the crystal made it necessary to resort to very intense positron sources for adequate counting statistics. The data presented here are the averages of several runs, each obtained with a 5 Ci source of ^{64}Cu without any change in the position of the Zr sample.

The result is shown in Fig. 1 and compared with the predictions by Gupta and Loucks.[1] For reference, the parabola of the free-electron gas is indicated also.

The experiment confirms that at small momenta the angular correlation curve of zirconium falls sig-

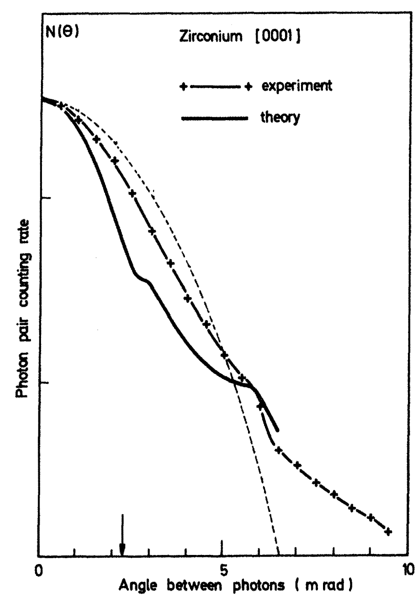

FIG. 1 Angular distribution of two-γ annihilation radiation of positrons in a zirconium crystal along the (0001) direction. Crosses indicate the experimental points and their statistical uncertainty. Solid curve is the results of the calculation by Gupta and Loucks (Ref. 1). Arrow indicates the position of the zone boundary. For comparison, the dashed curve presents the parabola of the corresponding free-valence-electron gas.

nificantly below the free-electron parabola. The small hump near the zone boundary predicted by the calculations of Gupta and Loucks is not resolved by the experiment. We observe however the hump predicted near $\theta = 6.5$ mrad. Thus the experiment supports the expectation of a pronounced contribution of the high-momentum components of the electron wave function where limitations in the convergence made the calculation somewhat uncertain.

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Phonon Effects in the Far-Infrared Reflectivity of Superconducting Lead*

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Measurements of reflectivity of evaporated films of lead at 1.2 °K show phonon structure above the energy gap. The frequencies of the peaks in the spectrum agree with phonon frequencies in lead observed by tunneling and neutron spectroscopy.

Recently, Joyce and Richards[1] reported absorptivity measurements on normal and superconducting lead single crstals in the region 15–200 cm^{-1} showing structure they associate with phonon generation. In this note, we report on similar experiments on evaporated films of lead. We evaporated films of about 1000 Å in thickness on the inside of a stainless steel nonresonant cavity at room temperature. Measurements were carried out at 1.2 °K with a Michelson interferometer and we estimate that the radiation makes an average of 100 reflections with the walls before reaching the antimony doped germanium bolometer. In this way small changes in the reflectivity are easily observable. We calculate the ratio of the bolometer signal in the superconducting state to the signal in the normal state. A magnetic field of 1500–3000 G was sufficient to drive the film normal as shown by electrical measurements.

Figure 1 shows the ratio of the bolometer signal in the superconducting state to the signal in the normal state for a typical film at 1.2 °K. Simple analysis shows that the ordinate is approximately proportional to the difference in absorbance of cavity walls for the two states. We find the energy gap 2Δ at 20 cm^{-1} followed on the high-frequency side by phonon structure very similar to that reported by Joyce and Richards. It consists of two peaks, one at 55 cm^{-1} and the other at 87 cm^{-1}. Additional structure is evident at 42, 61, 75, and 102 cm^{-1}. At frequencies above 120 cm^{-1}, the curve rises smoothly and rapidly and levels off at 210 cm^{-1}.

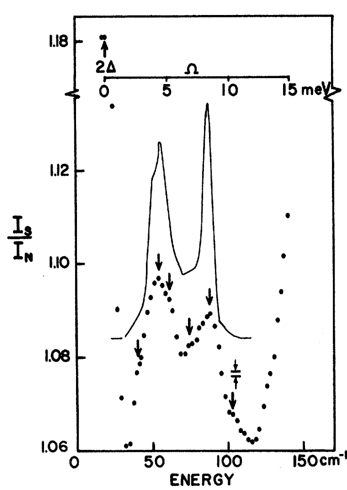

FIG. 1. Far-infrared reflectivity of superconducting lead films. Points show the change in absorbed power when a magnetic field is turned on and the film turns normal. Arrows denote discontinuities in the spectrum that are reproducible from sample to sample. The energy gap is at 2Δ and the meV scale is measured from this point. The solid curve is $\alpha^2 F(\Omega)$ obtained from tunneling measurements in Ref. 2. The resolution along the energy scale is 5 cm^{-1}.